

Chapter 10 - Energy Dissipation

Outlet protection for culverts, storm drains, BMP outlets, and steep open channels is essential to preventing erosion from damaging downstream channels and drainage structures. Erosion problems at culverts or at the outlet from detention basins are a common occurrence. Determination of the flow conditions, scour potential, and channel erosion resistance shall be standard procedure for all designs.

Outlet protection can be a channel lining, structure, or flow barrier designed to lower excessive flow velocities and prevent erosion and scour.

Outlet protection shall be employed whenever the velocity of flow at a pipe or open channel outlet exceeds the erosive velocity of the immediate downstream reach.

Energy dissipation may take the form of the following:

- Erosion control stone-lined channels;
- Riprap outlet basins; or
- Concrete baffled outlets.

10.1 References

Except where more stringent requirements are presented in this Design Manual, energy dissipators shall comply with VDOT and other state requirements. The primary design references are the VDOT Drainage Manual and the VA E&SC Handbook. Other appropriate references include:

- VDOT Standards
- VA SWM Handbook
- FHWA Design of Riprap Revetment HEC No. 11 (Pub. No. FHWA-IP-89-016 1989/2000)
- FHWA Hydraulic Design of Energy Dissipators for Culverts and Channels HEC No. 14 (Pub. No. FHWA-EPD-86-110 Sept. 1983 & FHWA-IF-00-02 2000)
- U.S. Dept. of the Interior – Bureau of Reclamation: Hydraulic Design of Stilling Basins and Energy Dissipators (Engineering Monograph No. 25)
- U.S. Dept. of the Interior – Bureau of Reclamation: Design of Small Canal Structures

10.2 Design Methodology and Criteria

10.2.1 Outlet Velocity

Where the outlet velocity from culverts, storm drain outfalls, or open channels is high, and channel or pipe modifications cannot adequately reduce the velocity, energy dissipation may be necessary. See the VDOT Drainage Manual for methodologies to determine design outlet velocities from open channels, culverts, and storm drains.

For the calculation of open channel velocity, see Chapter 5.

For the calculation of exit velocity from culverts, see Chapter 6.

For the calculation of exit velocity from storm drain pipes, see Chapter 7.

10.2.2 Erosion Control Stone

The most common form of energy dissipation is the use of erosion control stone at the outlet. Protection is provided primarily by having sufficient length and flare to dissipate energy by expanding the flow. The outlet velocities are computed for the design discharge and the 25-year discharge. Whichever velocity is the highest is used for energy dissipation design.

Where a pipe discharges into a channel, the apron shall extend across the channel bottom and shall extend up the bank to a depth of one foot above the maximum tailwater depth from the design storm event. The dimensional requirements of the erosion control stone apron shall be determined using the graphical curves in the VA E&SC Handbook.

Generally, the use of erosion control stone for energy dissipation is limited to a maximum velocity of 19 feet per second. Alternative means of energy dissipation shall be required where the discharge velocity is greater than 19 feet per second. Alternative means include riprap outlet basins or concrete baffled outlets. The use of alternative means of energy dissipation requires the approval of VDOT when located in a VDOT right-of-way.

10.2.3 Riprap Outlet Basins

A riprap basin is a depressed area of riprap placed at the outlet of a high velocity culvert, storm drain outlet or open channel. The riprap reduces the exit velocity by expanding the flow over the riprap length and width and forming a hydraulic jump.

For the design of riprap basins, refer to the VDOT Drainage Manual. Dissipator geometry may also be computed using the “Energy Dissipator” module that is available in the computer program FHWA HY8, Culvert Analysis.

Details of the riprap basin energy dissipator are included in Appendix 10A.

10.2.4 Baffled Outlets

A baffled outlet usually consists of a concrete box structure with a vertical hanging concrete baffle and an end sill. Several variations of concrete baffled outlets have been published by VDOT and other state and local transportation and stormwater management agencies. A typical schematic of baffled outlets are shown in Appendix 10C. Baffled outlets are usually used when very high exit velocities exist at piped or channel transitions. Baffled outlets function by dissipating energy through impact of the water hitting the baffle and through the resulting turbulence. A tailwater depth is not required for adequate energy dissipation, but will help smooth the outlet flow.

This type of outlet protection may be used with outlet velocities up to 50 feet per second.

Baffled outlets are not included in state guidance handbooks. Hydraulic design procedures for baffled outlets may be found in the U.S. Department of Interior, Bureau of Reclamation, Design of Small Canal Structures, 1978 and are as follows:

Step 1: Determine input parameters, including:

H = Energy head to be dissipated, feet (can be approximated as the difference between channel invert elevations at the inlet and outlet).

Q = Design discharge, cubic feet/second

v = Theoretical discharge velocity determined from $2 g H$, feet/second

A = Flow area, Q / v , feet²

d = Flow depth entering the basin, ft

Fr = Froude number = $v / (g d)^{0.5}$, dimensionless

g = Gravitational constant = 32.2 feet/second²

Step 2: Calculate the minimum basin width, W, in feet, using the following equation:

$$W / d = 2.88 (Fr)^{0.566}$$

Where:

W = minimum basin width, feet

d = depth of incoming flow, feet

Fr = Froude number = $v / (g d)^{0.5}$

The limits of the W/d ratio are from 3 to 10, which corresponds to Froude numbers 1 to 9. If the basin is much wider than W , flow will pass under the baffle and energy dissipation will not be effective.

Step 3: Calculate other basin dimensions as a function of W .

Refer to the Schematic of Baffled Outlet in Appendix 10CA for other dimensions as a function of W and to identify variables that are used below in other steps.

Step 4: Calculate the required protection for the transition from the baffled outlet to the natural channel based on the outlet width.

A riprap apron shall be added of width W , length W (or a 5-foot minimum), and depth f ($W/6$). The side slopes shall be 1.5:1, and the median rock diameter shall be at least $W/20$.

Step 5: Calculate the baffled outlet invert elevation based on the expected tailwater.

The maximum distance between expected tailwater elevation and the invert should be $b+f$ or some flow will go over the baffle with no energy dissipation. If the tailwater is known and fairly controlled, the baffled outlet invert should be a distance $(b/2) + f$ below the calculated tailwater elevation. If tailwater is uncontrolled, the baffled outlet invert should be a distance f below the downstream channel invert.

Step 6: Calculate the outlet pipe diameter entering the basin assuming a velocity of 12 fps flowing full.

Step 7: If the entrance pipe slopes steeply downward, the entrance pipe shall be turned horizontal for at least 3 feet before entering the baffled outlet.

Step 8: If it is possible that both the upstream and downstream ends of the pipe will be submerged, provide an air vent approximately $1/6$ of the pipe diameter near the upstream end to prevent pressure fluctuations and possible surging flow conditions.

10.2.5 Energy Dissipator for Paved Areas

For energy dissipation from velocities from paved channels or flumes, use VDOT Standards. Schematics of energy dissipators for paved flumes has been included in Appendix 10C.

10.2.6 Additional Energy Dissipators

For additional energy dissipators, refer to FHWA HEC No 14 entitled, Hydraulic Design of Energy Dissipators for Culverts and Channels.

10.3 Installation Requirements

Energy dissipators shall be installed and constructed according to all applicable FHWA, VDOT, and other state requirements and recommendations.

10.4 Easements

Where an energy dissipater will be owned by a public jurisdiction or agency, a drainage easement must encompass the entire energy dissipator, and provide an additional area 10 feet wide around the entire energy dissipator to provide for maintenance.

10.5 Environmental Impacts

Construction or modifications to energy dissipation structures shall comply with all applicable laws and regulations. The applicant is responsible for procuring all necessary permits, such as US Army Corps of Engineers and VA DEQ Wetland Permits, etc.

10.6 Maintenance Requirements

The permittee is responsible for maintenance of energy dissipation structures until construction is complete, including final clean up and site stabilization, to the satisfaction of the County. After the completion of construction, property owners or responsible parties are responsible for maintenance of all energy dissipation structures located in private easements.

APPENDIX 10A**AIDS FOR ENERGY DISSIPATION DESIGN****FROM VDOT DRAINAGE MANUAL**

Figure 8E-1, Details of Riprap Basin Energy Dissipator

Figure 8E-3, Riprap Basin Design Checklist

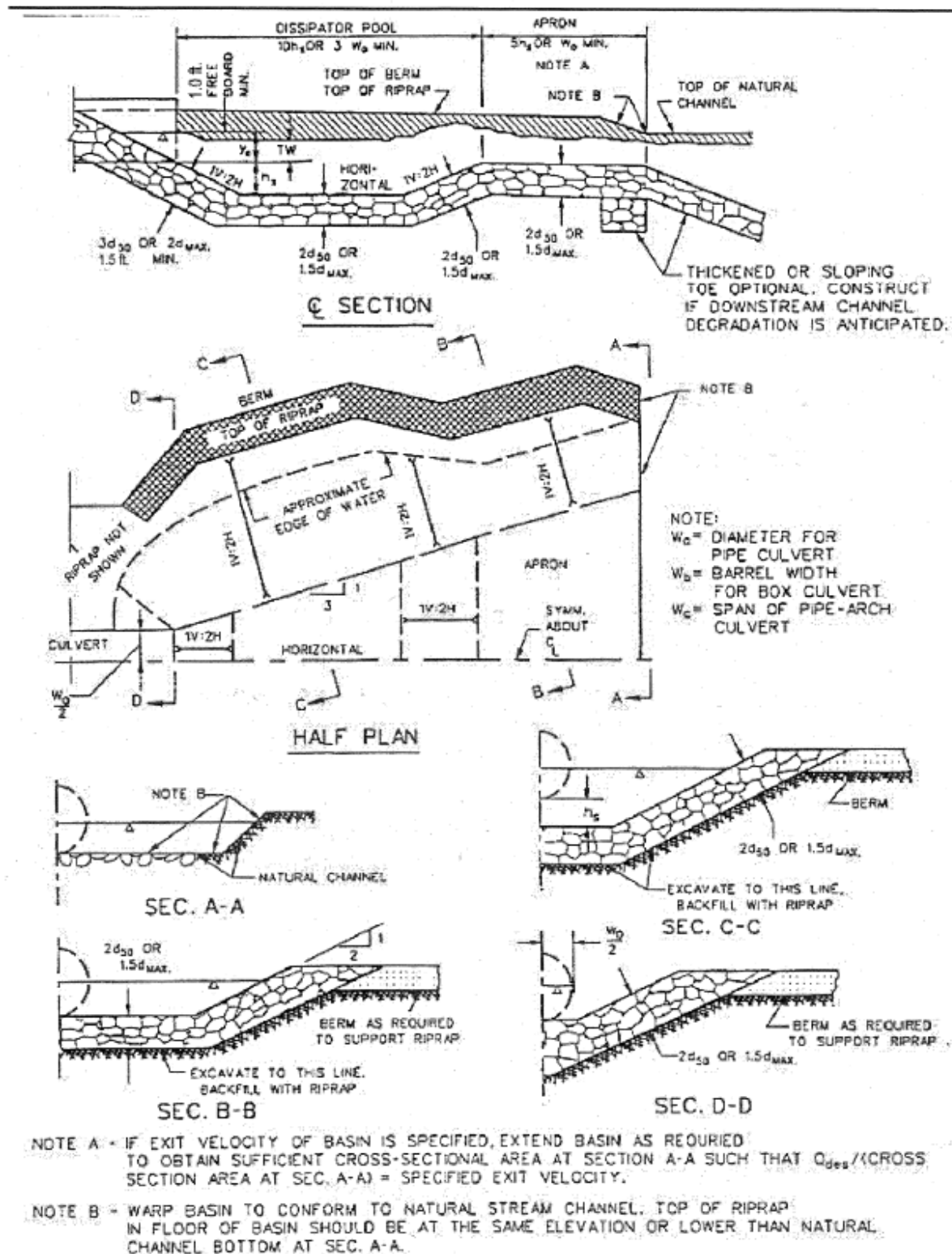


Figure 8E-1. Details of Riprap Basin Energy Dissipator

RIPRAP BASIN

Project No. _____

Designer _____

Reviewer _____

Date _____

Date _____

CULVERT BRINK

DISSIPATOR POOL

APRON

DESIGN VALUES (Figure 8E-2)	TRIAL 1	FINAL TRIAL
Equi. Depth, d_e		
D_{50}/d_e		
D_{30}		
Froude No., Fr		
h_2/d_e		
h_1		
h_2/D_{30}		
$2 < h_2/D_{30} < 4$		

BASIN DIMENSIONS		FEET	
Pool length is the larger of:	$10h_2$		
	$3W_u$		
Basin length is the larger of:	$15h_1$		
	$4W_u$		
Approach Thickness	$3D_{30}$		
Basin Thickness	$2D_{30}$		

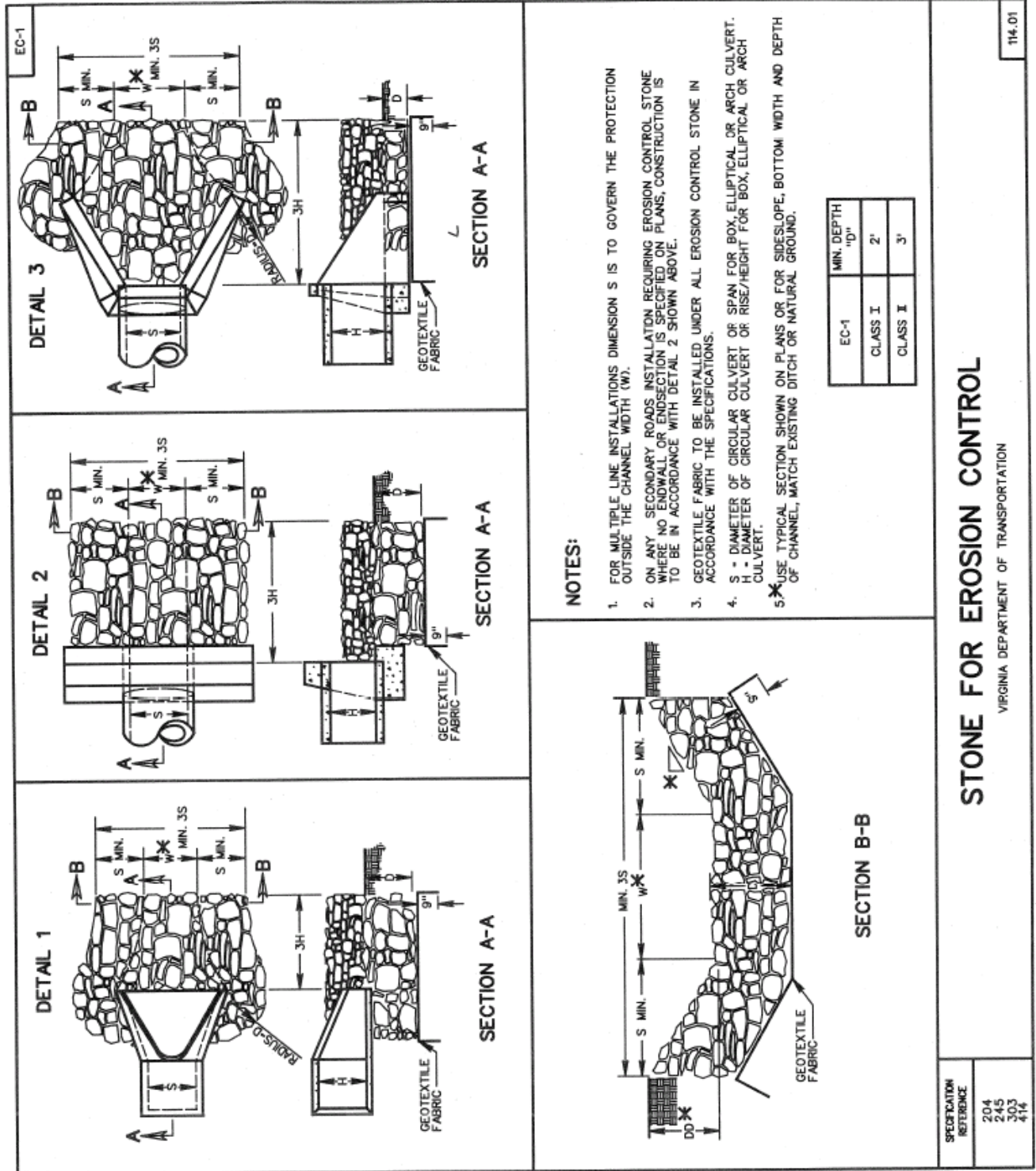
TAILWATER CHECK	
Tailwater, TW	
Equivalent depth, d_1	
TW/d_1	
IF $TW/d_1 > 0.75$, calculate riprap downstream using Figure 8E-4	
$D_e = (4A_v/\pi)^{0.5}$	

DOWNSTREAM RIPRAP (Figure 8E-4)				
L/D_1	L	V_L/V_u	V_L	D_{30}
10				
15				
20				
21				

Figure 8E- 3. Riprap Basin Design Checklist

APPENDIX 10B**AIDS FOR ENERGY DISSIPATION DESIGN
FROM VDOT ROAD AND BRIDGE STANDARDS**

Standard 114.01, Stone for Erosion Control



APPENDIX 10C**ENERGY DISSIPATION DESIGN SCHEMATICS**

Schematics of Baffled Outlet, from US Bureau of Reclamation, Design of Small Canal Structures (as used by the State of Georgia and State of Colorado)

Standard Energy Dissipator for Use with Paved Flume, from VDOT Road and Bridge Standards

Precast Energy Dissipator, from VDOT Road and Bridge Standards

Various Energy Dissipators and Stilling Basins, from City of Knoxville, TN BMP Manual

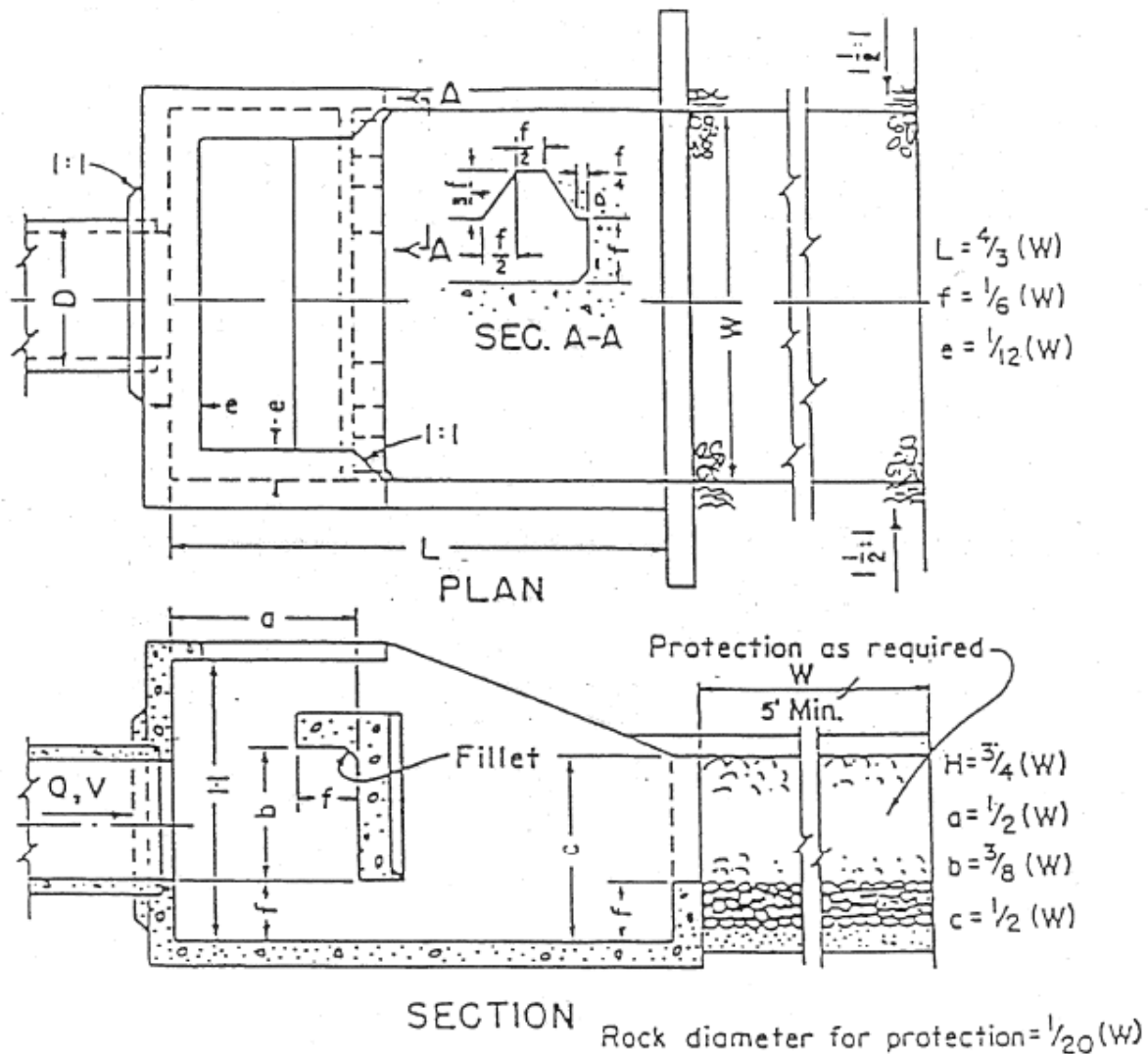


Figure 4.5-11 Schematic of Baffled Outlet
(Source: U.S. Dept. of the Interior, 1978)

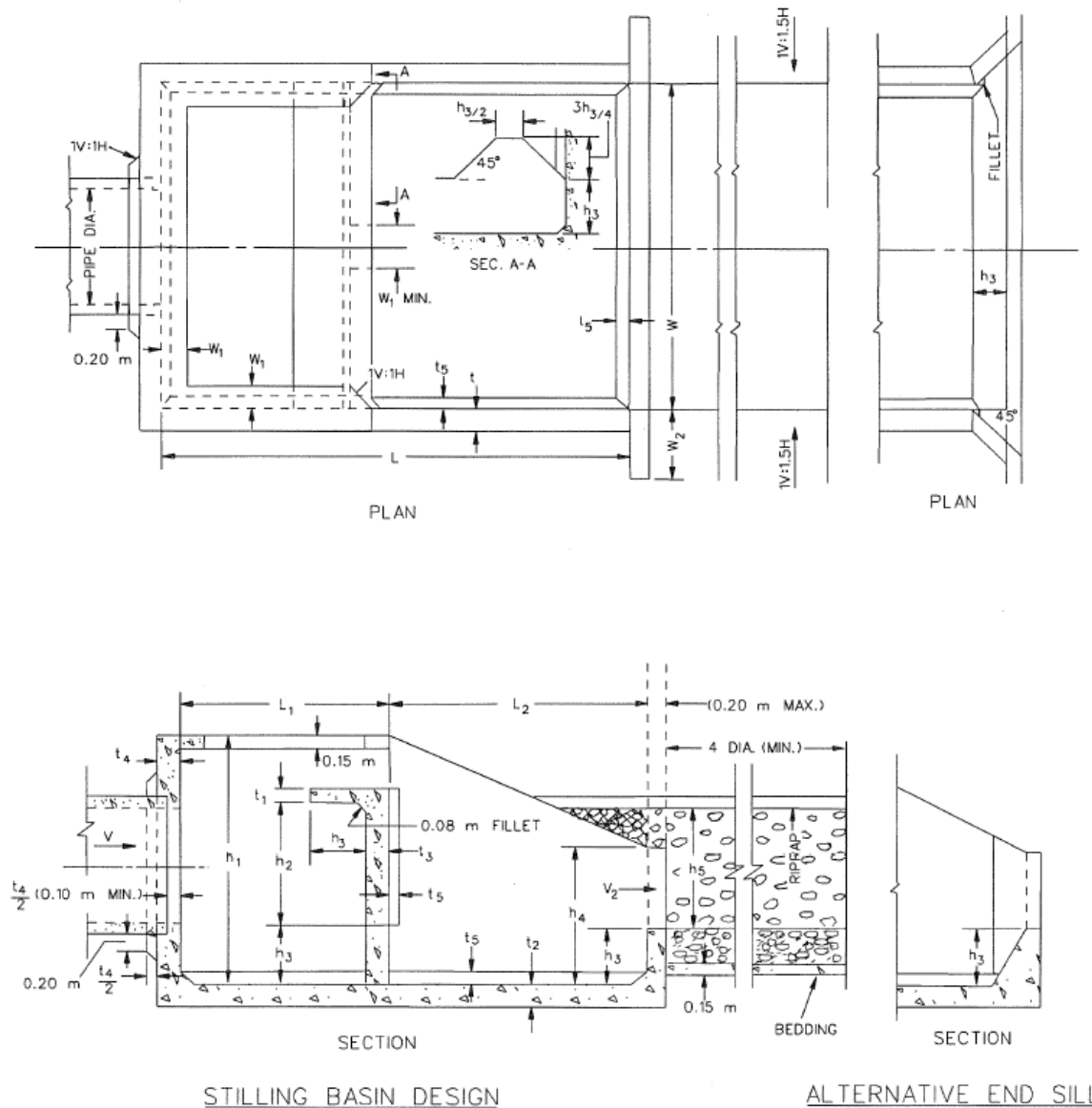
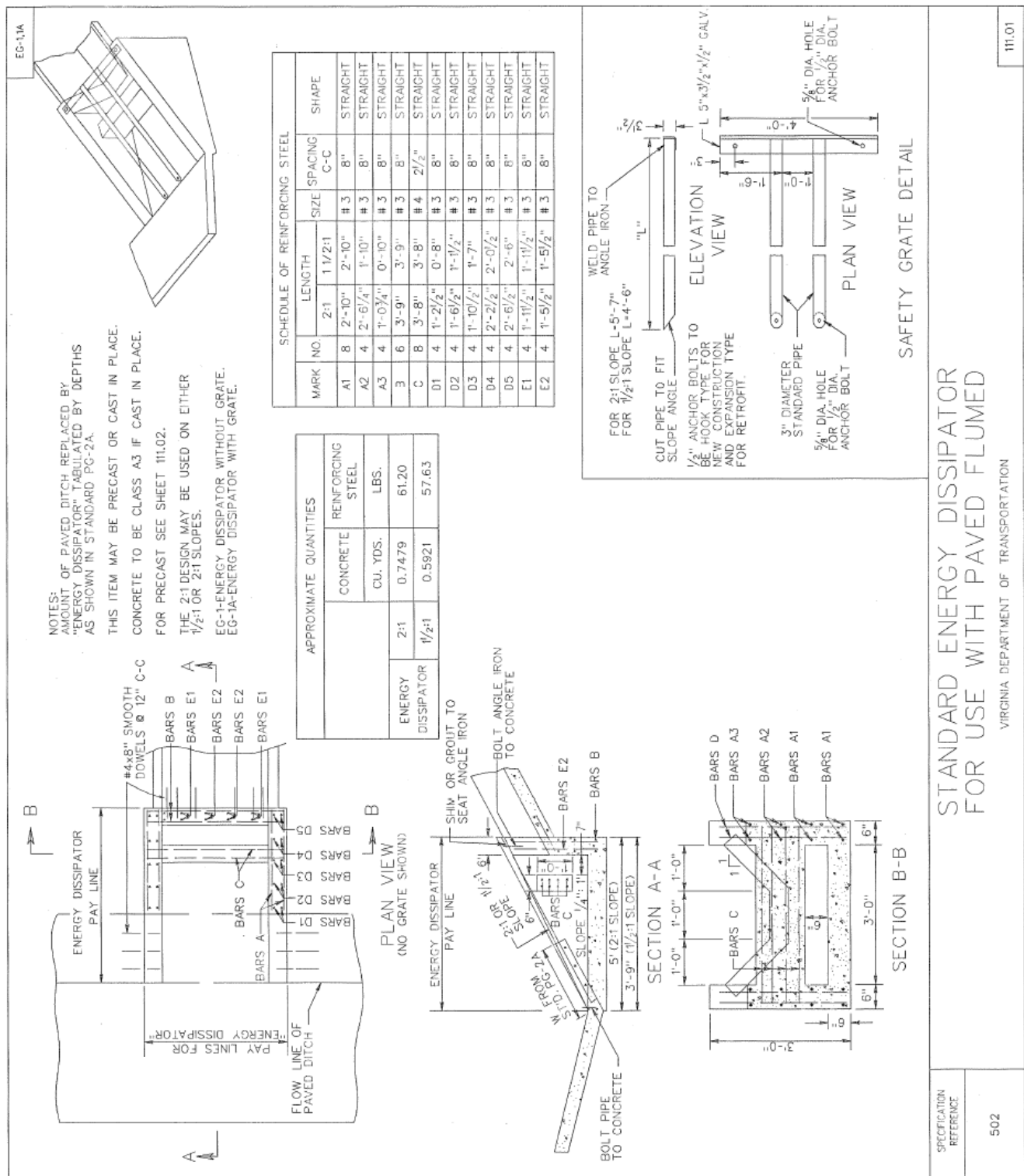


Figure 11.7 USBR Type VI (Impact) Dissipator



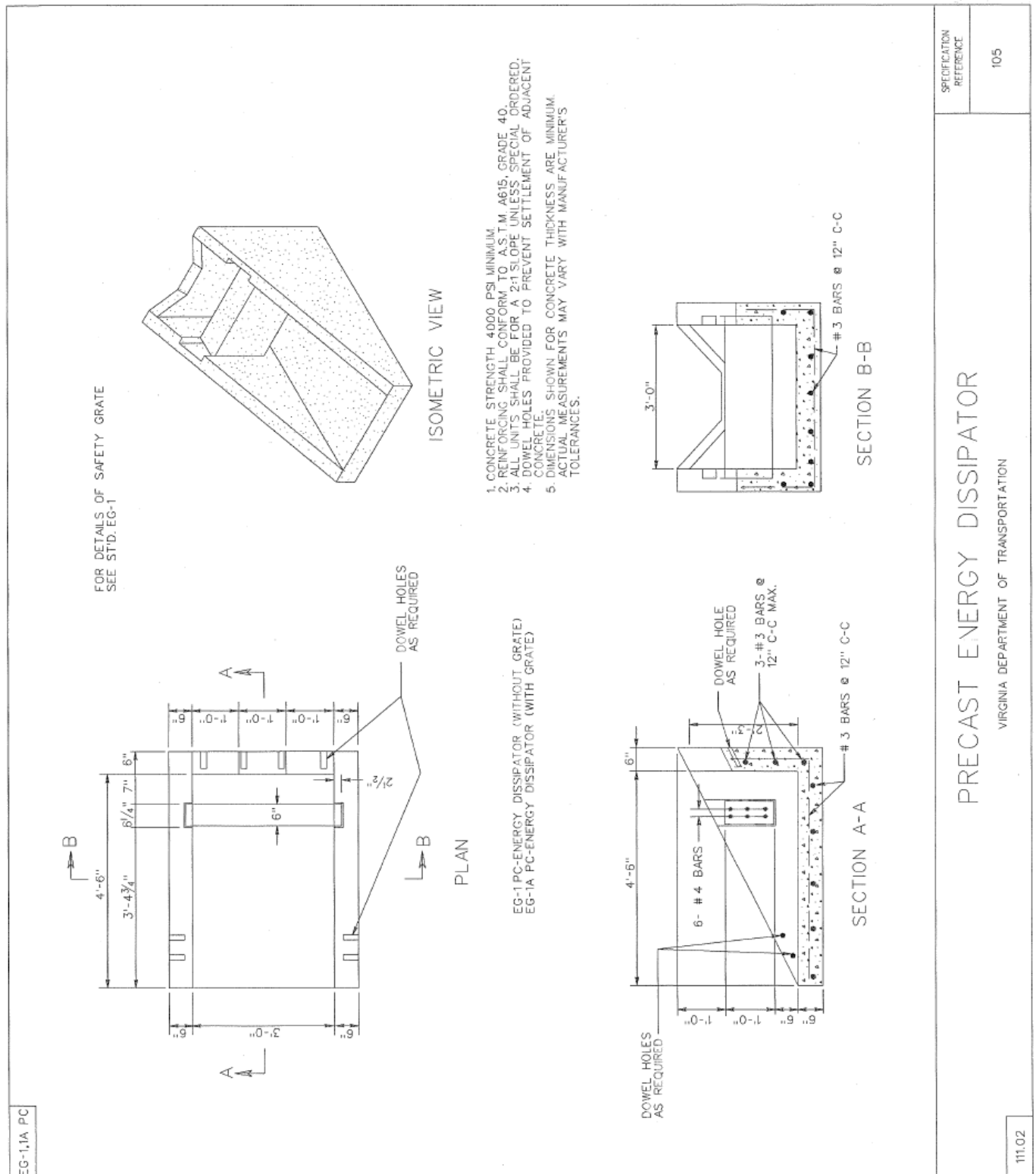
SPECIFICATION REFERENCE

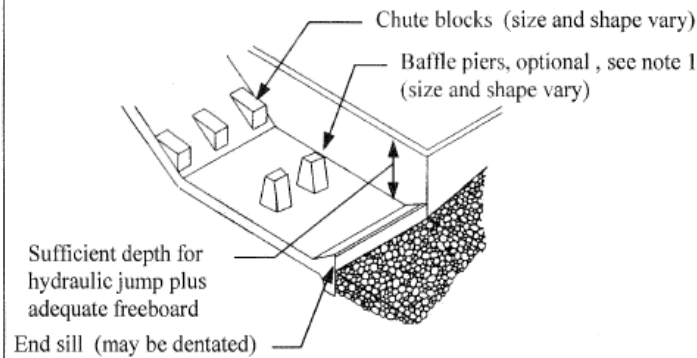
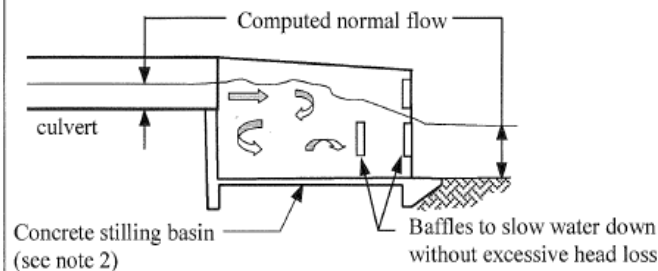
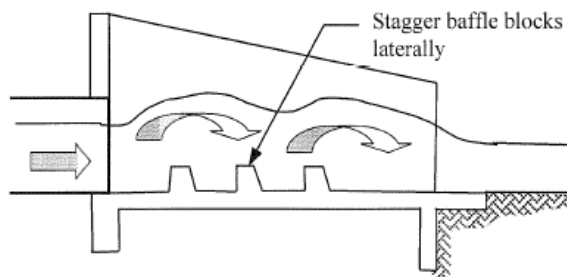
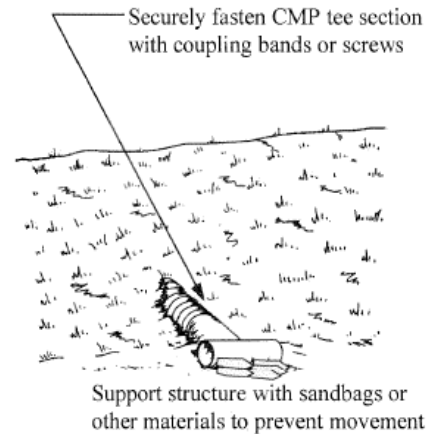
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STANDARD ENERGY DISSIPATOR
FOR USE WITH PAVED FLUMED

VIRGINIA DEPARTMENT OF TRANSPORTATION

11I.01



ACTIVITY: Outlet Protection**ES – 25****Typical Stilling Basin At End of Paved Flume or Chute****Typical Stilling Basin Using Baffles and Elevation Drop****Typical Energy Dissipator – Baffle Blocks Within Headwall****Temporary CMP Energy Dissipator****Notes:**

1. This is the basic format for several types of stilling basins. USBR Type II basin does not contain baffle piers, but does have a dentated end sill. USBR Type III basin has baffle piers and a smooth undentated end sill. See HEC-14 for detailed design of concrete structures.
2. Concrete stilling basin should be approximately as wide as the downstream channel. Design baffles to retain sufficient stormwater to act as a plunge pool for a wide range of flow values.

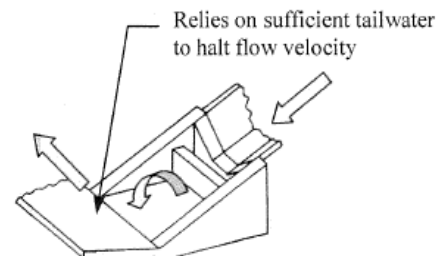
**Typical Impact Energy Dissipator (Virginia DOT)****NOT TO SCALE**

Figure ES-25-2
Various Energy Dissipators and Stilling Basins